Location Aware Systems for Mine and Industrial Worker Safety

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Q-TRACK®
The Q-Track Corporation
www.q-track.com

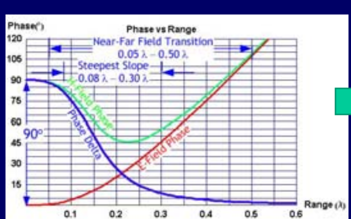
Innovative Wireless Real-Time Location Systems

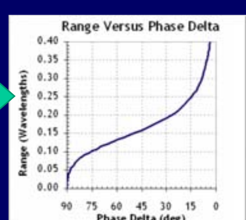
What NFER® Can Do

- Save lives by locating mine workers during an emergency
- Protect workers by training them to be aware of environmental hazards
- Lower the cost of federally mandated locating systems for mines
- Minimize worker exposure to environmental hazards

A Description of NFER® Technology

- Near-Field Electromagnetic Ranging
- Exploits near-field phase behavior to obtain location
- Low frequency (typically 0.5-1.7 MHz)
  - Diffracts around corners, enabling non-line-of-sight operation
  - Couples to conducting infrastructure to increase range
  - Penetrates non-conductive coal pillars
  - Resistant to multipath interference





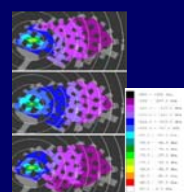
Relative phase differences provide a robust measurement of distance

The Technical Goals

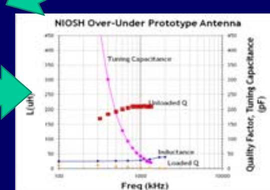
- Ruggedized long range system
- Permissible equipment rating for tag and locator
- Compact, efficient, low maintenance design
- Demonstrate NFER® rescue system

The Results to Date

- Propagation study in safety research mine and Huntsville's Three Caves show propagation to ~300 ft at 1 Watt power
- Theoretical calculations show 1k ft range at 5-10W using reasonably sized (~4 in) antennas
- Antenna candidate testing shows several dB gain over current Q-Track commercial antenna



Theoretical calculations match experimental propagation data at 0.5 W



Early antenna prototype testing shows promising gain results

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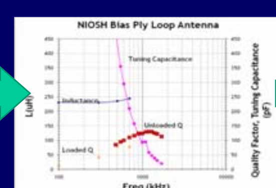
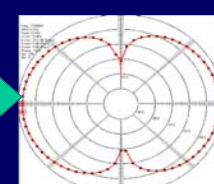
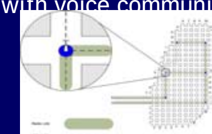




System Design

- Redundant fiber optic and/or 900 MHz wireless Ethernet data backbone
- 1-2k ft locator spacing
- Explosion-proof electronic enclosure, intrinsically safe external locator antennas
- Permissible tag powered by helmet light battery, with voice communications capability



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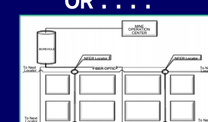

Fiber Optic and Wireless Ethernet mesh network technologies provide redundant data and voice transmission

Explosion proof enclosures and humi-seal potted electronics provide protection against ignition hazards such as coal dust and methane gas mixtures

The Current Product

- QT™-500 Dosimetry Simulation System enables realistic ALARA training for nuclear power plant workers

A QT™-500 Locator (Shown mounted to a tripod) and a QT™-500 Dosimeter Simulation Tag make up the core of the QT™-500 Dosimeter Training System

The work herein described was funded in part by contracts or grants from Homeland Security, The US Army, The National Science Foundation, the Defense Advanced Research Projects Agency, National Institute of Environmental Health Sciences, and The National Institute of Occupational Safety and Health.

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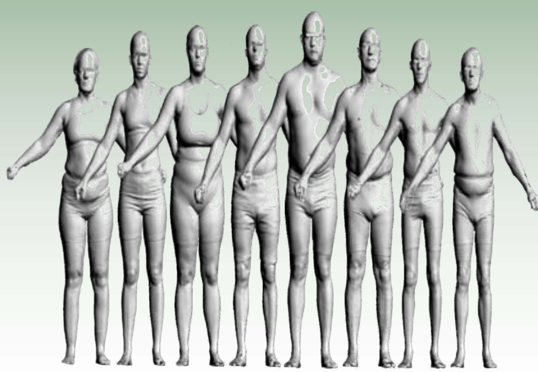
Understanding Harness Fit for Better Fall Protection

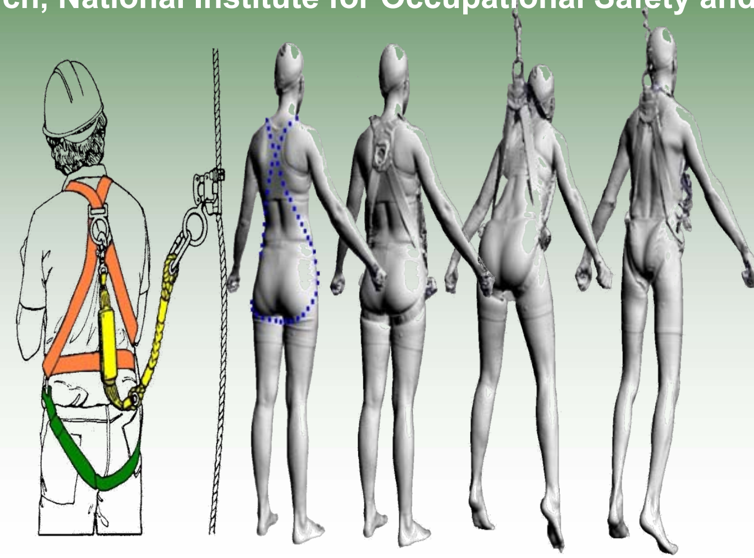
Hongwei Hsiao, Ph.D., Chief, Protective Technology Branch

Division of Safety Research, National Institute for Occupational Safety and Health, Morgantown, WV

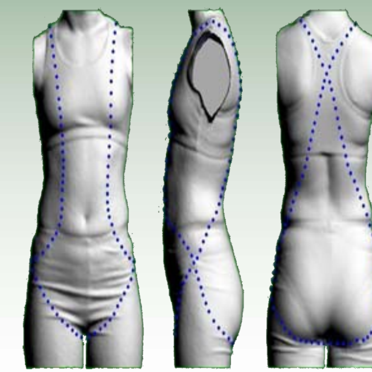
Background



Updated harness design for fall protection is needed to accommodate a wider range of body sizes and weights as well as an increased participation by female workers in the current construction workforce.

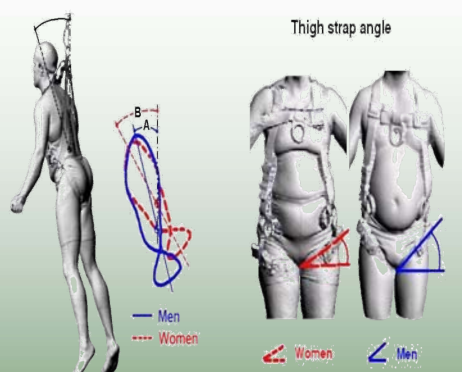


Objective and Method



Using the most current 3D whole-body digital scanning technology and a revolutionary body-shape quantification method, this project assembled data from the US workforce to establish an improved fall-arrest harness sizing system and design.

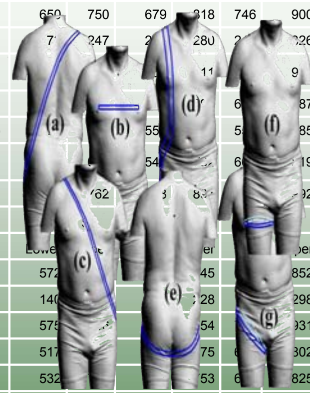
Outcome (1)



Increased inclination of torso suspension angle (hence fit failure) was associated with a reduction in torso length and a more developed chest; harnesses for women can to be designed with a more upward back D-ring than that of the current unisex design to mitigate this problem. Due to differences in pelvic structure, women have demonstrated a "flatter" thigh strap angle than men, which is correlated to fit failure. Harness thigh strap can be modified to accommodate pelvic configuration while overcoming suspension angle problem.

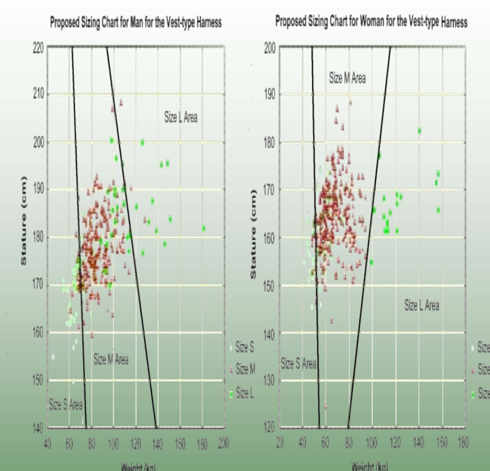
Outcome (2)

Male	Male S		Male M		Male L	
Harness Component	Lower	Upper	Lower	Upper	Lower	Upper
Back strap (a)	650	750	679	[illegible]	746	900
Chest strap (b)	[illegible]	247	[illegible]	280	[illegible]	[illegible]
Front cross-chest strap (c)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Front strap (d)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Gluteal Furrow Arc (e)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Thigh circumference (f)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Troch-Crotch cir. (g)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Female						
Harness Component	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Back strap (a)	572	[illegible]	[illegible]	[illegible]	[illegible]	852
Chest strap (b)	140	[illegible]	[illegible]	[illegible]	[illegible]	298
Front cross-chest strap (c)	575	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Front strap (d)	517	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Gluteal Furrow Arc (e)	532	[illegible]	[illegible]	[illegible]	[illegible]	825
Thigh circumference (f)	470	665	525	736	690	974
Troch-Crotch cir. (g)	577	781	617	849	806	1075



The study outcomes suggested an improved sizing scheme containing 3 sizes for women and 3 sizes for men in lieu of the current four- to seven-size unisex systems. The cut length and adjustment range for each harness strap were proposed.

Outcome (3)



The new sizing charts were graphed by gender, body weight, and body height for manufacturers' use to revise current systems or develop new designs.

Impact

This project provides both scientific theories and practical design and test criteria to advance harness configurations to reduce the risk of worker injury that results from poor user fit, improper size selection, or the failure to don the harness properly. The harness manufacturing industry has used the research results to formulate cost-effective harness-sizing schemes and the next generation harness designs for diverse populations, especially for women and minorities, to provide the required level of protection, productivity, and comfort.

Sizing Firefighters for Fire Apparatus Design

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1. Improved cab designs which can accommodate firefighters with variations in body sizes will help enhance safe operation of fire apparatus due to improved driver visibility and vehicle control operation.

2. Enhanced seat configurations which can accommodate firefighters with variations in body sizes will help increase post-crash survivability.

3. Enhanced body-restraint configurations which can accommodate firefighters with variations in body sizes and shapes will help increase post-crash survivability.

ABSTRACT

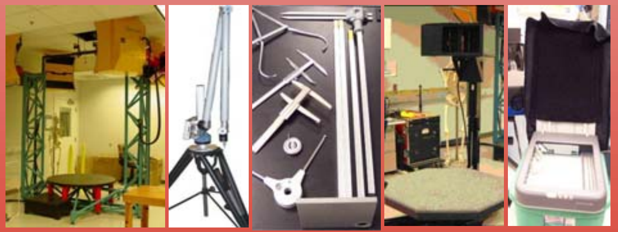
There are an estimated 1,136,650 firefighters in the U.S. The average rate of fatal workplace injuries to firefighters was 16.5 per 100,000 employed for the period 1992-97, which is 3.5 times more than all workers. In addition, firefighters sustain approximately 100,000 injuries per year. Inadequate fire apparatus fit to firefighters is perceived as a safety issue within the fire fighter community; anthropometrically correct fire apparatus will help reduce the exposure of firefighters to fatal and non-fatal injuries. This presentation describes a new effort to establish a large-scale anthropometric database of U.S. firefighters for the design of ergonomically efficient automotive fire apparatus. The database will consist of anthropometric data for 900 firefighters and workspace data for 495 firefighters, who will be selected as representative of the U. S. firefighter population in age, gender, and race/ethnicity. The database will include traditional anthropometric measurements, digital scans, and fire-truck cab workspace measurements. Results from this study will be applied to the updating of relevant NFPA standards on fire apparatus and the design of fire-engine cabs, seats, restraint systems, egress, and firefighter bunker gear. In collaboration with the National Fallen Firefighters Foundation (NFFF), the International Association of Fire Chiefs (IAFC), the International Association of Fire Fighters (IAFF), the Safety Task Force of NFPA 1901 Fire Apparatus Standards Committee, Total Contact Inc., and the Fire Apparatus Manufacturers Association (FAMA), NIOSH will begin the data collection in early 2010 in 4 areas (Phoenix, AZ; Chicago, IL; Rockville, MD; and Fort Worth, TX).

Data Collection Site	Male									Female			Total
	White			Black			Hispanic/Other						
age	18-32	33-44	45-65	18-32	33-44	45-65	18-32	33-44	45-65	18-32	33-44	45-65	
Phoenix, AZ	45	45	45	3	3	3	13	13	13	7	7	7	303
Chicago, IL	52	52	52	6	6	6	3	3	3	7	7	7	297
Rockville, MD	53	53	53	8	8	8	5	5	5	7	7	7	318
Fort Worth, TX	60	60	60	13	13	13	9	9	9	9	9	9	402
Total	630			90			90			90			900

7. The sampling plan for this study takes into account the geographic density of racial/ethnic distributions calculated from U.S. Census 2000.

4. Improved ingress/egress settings which can accommodate firefighters with variations in body sizes will help mitigate fall risks.

5. Updated firefighter anthropometry, which can improve the sizing of protective gear, will help reduce firefighter exposure to health and safety problems from poor fit (due to variations in body sizes and shapes), improper size selection, or the failure to don bunker gear properly.



6. A Cyberware whole body laser scanner (WB4), a FaroArm digitizer, a set of anthropometers and calipers, a head scanner, and a hand scanner will be used for this study.

Effect of Boot Weight and Material on Gait Characteristics of Men and Women Firefighters

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Abstract

Fifteen men and fifteen women firefighters were tested for regular gait or gait while carrying hose while wearing rubber or leather boots of varying weights. Spatio-temporal gait parameters and kinematics of firefighters were evaluated during simulated firefighting tasks. The increases in the double support time (%) when wearing heavier boots suggest greater energy cost and a longer time was needed for the body to re-establish stability from one step to another. There were significant reductions in sagittal and frontal ranges of motion at the ankles ($p<0.05$) and increases in peak ankle dorsiflexion and knee adduction angles ($p<0.05$) when wearing rubber boots. As the weight of the boots increased, ankle ranges of motion decreased. This study demonstrates that boot types affect firefighters' gait characteristics and lower extremity kinematics. Findings from this study are useful for firefighters and boot manufacturers in boot selection and design modifications, to reduce biomechanical stresses of the lower extremity and to improve gait performance.

Introduction

According to the National Fire Protection Association, an estimated 83,400 firefighter injuries occurred in the line of duty in 2006. The top two leading causes of injury were overexertion (25.5%) and falls (23.9%).[1] The firefighters' protective ensemble is designed to provide a high level of protection against extremely adverse environments; nevertheless, the use of PPE may pose an additional load on the firefighters, restricting their movements, impeding job performance, and increasing risks for overexertion and slip-trip-fall injuries. There are two general types of certified structural fire fighting boots in use today: 13"-16" rubber bunker boots and 8"-16" leather boots.[2] Rubber boots are approximately 3 pounds (1.4 kg) heavier than leather boots, while leather boots generally cost twice as much as rubber boots. Biomechanical and ergonomic studies of firefighter boots are scarce. There have been numerous studies on sport shoes and military boots[3-4]; however these findings cannot be generalized to firefighter boots. The objective of this study was to determine the effect of boot type and material on firefighters' gait characteristics and lower extremity joint movements during simulated firefighting tasks.

Methods

Fifteen men (31.8±5.2 years) and fifteen women (30.7±5.2 years) firefighters were recruited and each provided informed consent for this study. Men firefighters were recruited from the Morgantown area, while women firefighters were recruited from West Virginia, western Maryland, northern Virginia, and eastern Ohio. All subjects, while carrying a 10.5-kg backpack and wearing one of five randomly assigned pairs of safety shoes or firefighter boots, were tested for regular gait or gait while carrying a hose pack. Boot types and characteristics are shown in Table 1. Task order was randomized for each pair of boots. A motion-analysis system and two force plates were used to quantify gait and posture changes associated with different boots. Spatio-temporal gait parameters and lower extremity kinematics of firefighters were evaluated. Comparisons of boot material and boot weight were made using analysis of covariance with repeated measures.

Table 1. Footwear types and characteristics.

					
Type	**Light Leather**	**Heavy Leather**	**Light Rubber**	**Heavy Rubber**	**Safety Shoes**
Material	**Leather**	**Leather**	**Rubber**	**Rubber**	**Leather**
	2.6 kg men [illegible]	**2.9 kg men 2.5 kg women**	**3.3 kg men 3.0 kg women**	**3.9 kg men 3.4 kg women**	**1.4 kg men 1.2 kg women**

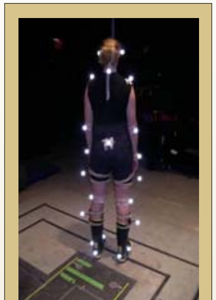

Figure 1. Marker system

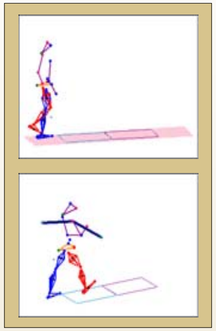

Figure 2. Gait and hose carrying task

Task	Gait Variable	Rubber Boots	Leather Boots	Safety Shoes
Gait	Stride Length (m)	1.67 (0.04)	1.67 (0.06)	1.69 (0.06)
	Step Width (m)	0.21 (0.08)	0.18 (0.06)	0.15 (0.05)
	Double Support (%)	21.5 (3.3)	20.6 (3.5)	19.5 (2.1)
	Speed (m/sec)	1.16 (0.10)	1.20 (0.09)	1.25 (0.16)
Hose	Stride Length (m)	1.66 (0.06)	1.67 (0.05)	1.69 (0.06)
	Step Width (m)	0.21 (0.08	0.19 (0.06)	0.15 (0.05)
	Double Support (%)	22.6 (3.0)	22.7 (2.9)	20.1(1.9)
	Speed (m/sec)	1.12 (0.08)	1.12 (0.09)	1.20 (0.14)

Table 2. Means of Temporal Gait Variables

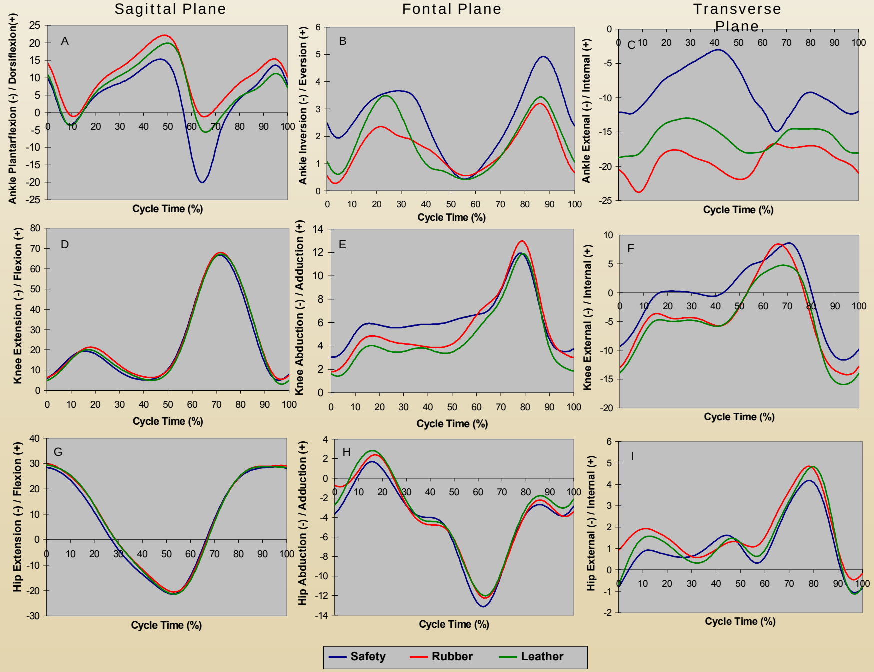

Figure 3. Comparison of joint angular motions for different types of footwear at ankles (A,B,C), knees (D,E,F), and hips (G,H,I) averaged over all subjects for three anatomical planes

Results

Subjects' average walking speed was significantly reduced from 1.25 m/s for safety shoes to 1.16 m/s for rubber boots ($p<0.05$). Similar trend was found for gait while carrying a hose pack; however, the walking speed was reduced (Table 2). Subjects' mean step width was 15 cm for gait with safety shoes and it was significantly increased to as much as 21 cm for rubber boots ($p<0.05$). The percentages of double stance period for gait with rubber (21.5) or leather boots (20.6) were found to be significantly greater than that of safety shoes (19.5). There was no effect found on stride length due to boot type. A gender effect was found for walking speed and stride length ($p<0.05$).

Considerable differences were observed when comparing ankle joint angles among different types of footwear (Figure 3(A,B,C)). The effect of boot type was found to be significant for peak ankle plantarflexion, eversion, and external angles ($p<0.05$). The ankle ranges of motion for gait with rubber or leather boots were significantly reduced compared to safety shoes in all three anatomical planes. The sagittal ankle angle profiles were considerably different from gait with safety shoes with a characteristic of little to no plantarflexion (Figure 3A).

The knee flexion, hip flexion/extension, and hip abduction/adduction angle patterns among different types of footwear were generally identical (Figure 3(D,G, H)). Significantly greater peak ankle dorsiflexion and knee adduction angles were observed for rubber boots (Figure 3 (A,E)).

Discussion

The significant increases in double support time (%) for heavier boots suggest greater balance demand and energy cost during normal gait. A significantly greater percentage of double support also increased when the hose pack was carried than without it. This finding is consistent with previous research that the percentage of the stride under double support usually increases with the amount of weight carried.[5]

The predominant kinematic changes seen among different footwear types were at the ankle joints across all three anatomical planes. The restricted ranges of motion at ankles may result from the extra weight of boots and an increased resistance to ankle motions. Subjects may not able to effectively plantar-flex their ankles to provide an active push-off during the pre-swing phase of gait. The significant increase in peak ankle dorsiflexion and knee adduction angles during walking with rubber boots is considered undesirable because potentially greater torques in the frontal and sagittal planes may be transmitted up to legs, knees and hips. Future analysis on joint moments is needed to verify the balance control mechanism.

Conclusions

- Subjects adjusted their gait by increasing the percentage of double stance period and step width when wearing heavier boots. Such changes suggest greater energy cost and a longer time was needed for the body to re-establish stability from one step to another.
- In general, both rubber and leather boots were shown to significantly alter lower extremity joint motions. The most significant alterations were seen in ankle kinematics. Significant changes in knee and hip joint angles were also observed in the transverse plane.

References

1. Karter, MJ., Molis, JL. Firefighter injury for 2006. NFPA Journal, November / December 2007.
2. National Fire Protection Association. NFPA Standard 1971 – Structural Fire Fighting. 1 Batterymarch Park, Quincy, MA, 2000.
3. Rosenblad, W.: The design and evaluation of military footwear based upon the concept of healthy feet and user requirement studies. *Ergonomics, 31* (9): 1245-1263 (1988).
4. Hamill, J., P.S. Freedson, W. Boda and F. Reichsman. Effects of shoe type and cardiorespiratory responses and rearfoot motion during treadmill running. Medicine and *Sci. in Sports and Exer*, 20, 515-521 (1987).
5. Martin, PE and RC Nelson. The effect of carried loads on the walking patterns of men and women. *Ergonomics,* 29: 1191-1202 (1986).

Project HEROES® - EVALUATION OF THE PHYSIOLOGICAL STRESS IMPOSED BY A PROTOTYPE FIREFIGHTER ENSEMBLE WITH CHEMICAL/BIOLOGICAL HAZARD PROTECTION

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Background

- Firefighters experience a high number of injuries and fatalities due to cardiovascular events and heat stress
- NPPTL was asked to evaluate the cardiovascular and thermoregulatory response to the Project HEROES® prototype ensemble with additional chemical and biological hazard protection, which included a hose assembly to reroute expired SCBA air into the jacket for possible cooling purposes

Project HEROES® Goals

- Development of new materials and ensemble design to allow the production of a firefighting ensemble that will meet the requirements of NFPA 1971 and 1994
- Establish test methods and protocols to ensure that new technologies/designs can be tested appropriately
- Work closely with standards organizations to ensure that the current and future editions of standards will allow for inclusion of new technologies

Fig. 1: HEROES® prototype firefighter ensemble with chemical and biological hazard protection

Partnerships

Project HEROES® was funded externally by the Department of Defense's Technical Support Working Group (TSWG) and was managed by the International Association of Fire Fighters (IAFF)

Disclaimer: the findings and conclusions in this poster have not been formally disseminated by the National Institute for Occupational Safety and Health and should not be construed to represent any agency determination or policy.

This research was performed while one of the authors (Aitor Coca) held a National Research Council Resident Research Associateship at the National Personal Protective Technology Laboratory (NPPTL).

Study Design

- Subjects (n = 10) randomized as to the order of the garment tested
- Testing conducted in environmental chamber at 22 °C and 50% RH
- Compared the physiological responses of human subjects to wearing a standard ensemble (SE 1, SE 2 and SE tests average) or a prototype ensemble (PE with hose and PE without hose) while exercising at ~50% relative aerobic capacity
- Measured core body temp, regional skin temp (Tsk), sweat rate (measured as loss of body weight during testing), electrocardiogram (ECG), and heart rate (HR)

Fig. 2: Research subject wearing HEROES® prototype during exercise testing in an environmental chamber

Results

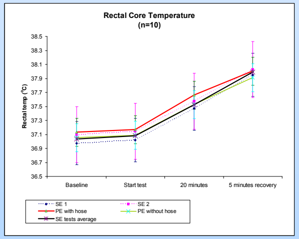

Fig. 3: Rectal temperatures of subjects wearing either the PE or SE during 20 min of treadmill exercise in an environmental chamber.

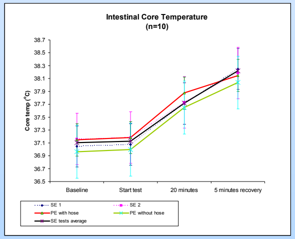

Fig. 4: Intestinal temperatures of subjects wearing either the PE or SE during 20 min of treadmill exercise in an environmental chamber.

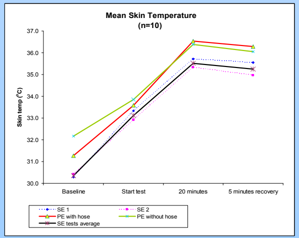

Fig. 5: Mean Tsk of subjects wearing either the PE or SE during 20 min of treadmill exercise in an environmental chamber.

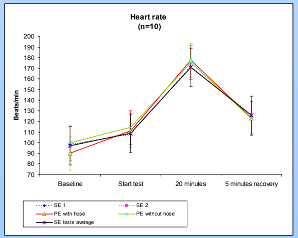

Fig. 6: HR of subjects wearing either the PE or SE during 20 min of treadmill exercise in an environmental chamber.

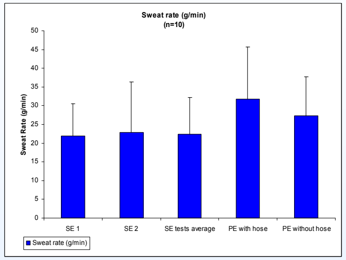

Fig. 7: Sweat rate of subjects wearing either the PE or SE during treadmill exercise in an environmental chamber.

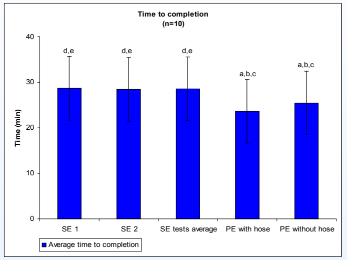

Fig. 8: Time to completion for subjects wearing either the PE or SE during treadmill exercise in an environmental chamber. *There was a significant difference between the standard ensemble (SE 1, SE 2, and average) and the prototype ensemble ($p < 0.05$). Superscripts indicate statistically significant differences ($p<0.05$) between tests; SE 1=a; SE 2 = b; SE tests average = c; PE with hose = d; PE without hose = e.

Conclusions

- "Core" and Tsk data suggest that that there is no difference in the thermal stress imposed on the subject between the PE and the SE
- Average weighted Tsk and HR suggest that the subjects wearing the PE with exhalation hose attached to the jacket experienced an elevated thermal stress compared to subjects wearing the PE without the hose being attached or wearing the SE
- There was a trend toward an increase in sweat rate in the PE compared to the SE; however, the differences did not reach statistical significance
- Subjects' time to completion wearing the PE with the exhaust hose was significantly less ($p < 0.05$) than the time to completion of the subjects wearing the SE. Subjects wearing the SE exercised on the treadmill an average of 5 min longer than while wearing the PE with the exhaust hose attached and an average of 3 minutes longer than while wearing the PE without the exhaust hose attached
- The additional chemical and biological hazard protection offered by the PE still allows the wearer to exercise for at least 20 minutes which is the practical duration of an SCBA while fighting a structural fire

CDC Workplace Safety and Health
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NPPTL Research to Practice through Partnerships

Physiological Consequences of Rubber and Leather Boots in Men and Women Firefighters

Nina L. Turner

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Abstract

Twenty-five men and 25 women firefighters walked on a treadmill and climbed a stair ergometer while wearing rubber and leather boots. During treadmill exercise, a 1-kg increase in boot weight caused significant ($p \leq 0.05$) increases in $\dot{V}_E$ (9.2%), $\dot{V}O_2$ (5.8%), $\dot{V}O_2$/kg (5.9%), $\dot{V}CO_2$ (7.8%), and HR (5.7%) for men and increases in $\dot{V}O_2$ (3.0%), $\dot{V}O_2$/kg (3.4%), and $\dot{V}CO_2$ (3.6%) for women. Gender differences in these increases may be due to the prior observation that as the weight of a carried load increases, women shorten their stride length while men do not. During stair ergometry, a 1-kg increase caused significant increases in $\dot{V}O_2$ (3.8%), $\dot{V}O_2$/kg (3.4%), $\dot{V}CO_2$ (3.1%) in men and increases in $\dot{V}CO_2$ (3.3%) in women, as well as a 4.1% increase in inhaled peak flow for both. The 3% increases seen during stair ergometry are less than the 5% increases observed in a previous study of leather and rubber boots where subjects wore no additional protective equipment. There were no significant effects of boot material on any variables during either mode of exercise.

Introduction

The intensity of energy expended by firefighters performing fire fighting tasks is generally agreed to be in the heavy to very heavy range. According to the National Fire Protection Association, an estimated 80,100 firefighter injuries occurred in the line of duty in 2005. The top two leading causes of injury were overexertion (24.1%) and falls (25.5%). Of all 115 firefighter fatalities in 2005, 55 were the result of heart attack. There are two general types of certified structural fire fighting boots in use today: 13"-16" rubber bunker boots and 8"-16" leather boots.(1) Rubber boots are approximately 3 pounds (1.4 kg) heavier than leather boots, while leather boots generally cost twice as much as rubber boots. A 5 – 12% increase in oxygen consumption per kg of weight added to the foot has been observed;(2,3) however, the increase may depend on gender, task, boot material, and whether or not subjects are wearing additional protective clothing or equipment.

Goal

The goal of the current study was to determine the effects of two leather and two rubber boots on men and women firefighters' metabolic variables during simulated firefighting tasks.

Stakeholders

- NFPA 1971 Technical Committee on Structural Firefighting Personal Protective Equipment
- Firefighters
- Boot manufacturers

Fig. 1 Treadmill walking

Methods

Twenty-five career men and 25 women (22 career, 3 volunteer) firefighters between the ages of 18 and 40 were recruited and provided informed consent for this study. Men (mean age 31 yrs, wt 93.4 kg, ht 178.2 cm) were recruited from the Morgantown, WV area, while women (mean age 32, wt 72.8 kg, ht 166.8 cm) were recruited from West Virginia, western Maryland, northern Virginia, and eastern Ohio. All subjects, while wearing full turnout clothing, a 10.5-kg backpack, gloves, helmet, and one of four randomly assigned pairs of firefighter boots, walked for 6 minutes at 3 mph on a treadmill while carrying a 9.5-kg hose (Fig. 1) and climbed a stair ergometer for 6 minutes at 45 steps per minute (6-inch step height, Fig. 2). Boot models and characteristics are shown in Table 1. Task order was randomized for each pair of boots. Minute ventilation ($\dot{V}_E$), oxygen consumption ($\dot{V}O_2$ and $\dot{V}O_2$/kg), CO_2 production ($\dot{V}CO_2$), heart rate (HR), and peak flow were measured using a portable metabolic measurement system (COSMED, Italy), and an average of the breath-by-breath data from minute six was used for analysis. Comparisons of gender, boot material, and boot weight were made using analysis of covariance with repeated measures.

Table 1. Boot Models and Characteristics

Material	Sole	Weight	Height	Heel Area
Leather (2 models)	Stitched	2.7 kg men 2.4 kg women	36.8 cm	81.3 cm2
Rubber (2 models)	Rubber	3.6 kg men 3.2 kg women	40.6 cm	71.0 cm2

Results and Discussion

During treadmill walking, significant effects of boot weight ($p \leq 0.05$) were observed for all variables except peak flow. Significant gender differences ($p \leq 0.05$) were observed for $\dot{V}O_2$, $\dot{V}O_2$/kg, $\dot{V}CO_2$, and HR. During stair ergometry, significant effects of boot weight ($p \leq 0.05$) were observed for all variables except HR and exhaled peak flow. Significant gender differences ($p \leq 0.05$) were observed for $\dot{V}O_2$, $\dot{V}O_2$/kg, and $\dot{V}CO_2$. There were no significant additional effects of boot material on any variables during either mode of exercise. Table 2 shows the estimated percent increase per 1-kg increase in boot weight for metabolic and respiratory variables significantly affected by boot weight. A 9.2% increase in $\dot{V}_E$, observed in men during treadmill walking, would result in an approximate 8% decrease in service time for a 45-min SCBA cylinder.

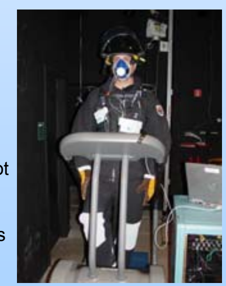

Fig. 2 Stair ergometry

Lesser increases due to boot weight in women's variables while walking may be due to the prior observation that as the weight of a carried load increases, women shorten their stride length while men do not.(4) Boot weight equaled approximately 3.5% of body weight for men and 4% for women. However, total gear and hose weight equaled approximately 33% of men's body weight and 42% of women's body weight; the greater relative load carried by the women firefighters may have further diminished the effect of boot weight. Likewise, the 3% increases seen during stair ergometry are less than the 5% increases observed in a previous study of leather and rubber boots where subjects wore only gym shorts.(5)

Table 2. Significant Percent Increase per kg Increase in Boot Weight ($p \leq 0.05$)

Task	$\dot{V}_E$ (L/min, BTPS)	$\dot{V}O_2$ (L/min, STPD)	$\dot{V}O_2$/kg (ml/kg//min, STPD)	$\dot{V}CO_2$ (L/min), STPD	HR (bpm	Inhaled Peak Flow (L/min, BTPS)
Treadmill						
Combined	5.7%	4.8%	4.7%	6.2%	3.4%	
Men	9.2%*	5.8%	5.9%	7.8%	5.7%	
Women		3.0%	3.4%	3.6%		
Stairs						
Combined	3.1%	2.6%	2.2%	3.2%		4.1%
Men		3.8%	3.4%	3.1%		
Women			3.3%			

* Significant ($p \leq 0.05$) interaction between gender and boot weight

Conclusions

- During treadmill walking a 1-kg increase in boot weight caused a significant ($p \leq 0.05$) ~5 to 6% increase in $\dot{V}_E$ and oxygen consumption for men and women combined, with a 9% increase in $\dot{V}_E$ in men only.
- During stair ergometry, a 1-kg increase in boot weight caused a significant ($p \leq 0.05$) ~3% increase in $\dot{V}_E$ and oxygen consumption, less than the 5% increases observed in subjects without turnout gear and SCBA's.(5)
- There was no significant effect of boot material in addition to boot weight.

References

1. National Fire Protection Association. NFPA Standard 1971 – Structural Fire Fighting. 1 Batterymarch Park, Quincy, MA, 2000.
2. Jones, B. et al. The energy cost and heart rate response of trained and untrained subjects walking and running in shoes and boots. Ergonomics, 27(8):895- 902 (1984).
3. Miller, J. and B. Stamford. Intensity and energy cost of weighted walking vs. running for men and women. J. Appl. Physiol. 62(4): 1497-1501 (1987).
4. Martin, PE and RC Nelson. The effect of carried loads on the walking patterns of men and women. Ergonomics, 29: 1191-1202 (1986).
5. Neeves, R. et al. Physiological and biomechanical changes in firefighters due to boot design modifications. Final Report. International Association of Firefighters and the Federal Emergency Management Association, August, 1989.

Disclaimer

"Reverse Engineering NFPA Standard 1971 – The Structural & Proximity Glove Sizing Standard"

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National Institute for Occupational Safety and Health

Abstract

Current sizing schemes for certified gloves worn by US firefighters include three sizing standards for medical gloves (NFPA 1999), one sizing standard for technical rescue gloves (NFPA 1951), one standard for leather wildland fire gloves (NFPA 1977), and one standard for the gloves used for structural and proximity fire fighting (NFPA 1971). The sizing criteria used in NFPA Standard 1971 was originally established in 1976 and was based on the hand anthropometry of male and female Air Force personnel collected during 1969 - 1970. This performance standard remained unmodified from its original uni-sex scheme until the fall of 2007, when two additional glove sizes were added to the original five size scheme (XS, S, M, L, and XL). However, the 2007 revision did not provide the specific sizing criteria for its two newest sizes (XXS and XXL). To fill in the missing sizing criteria, this presentation explores how the original data was statistically devised, and uses the same technique to reveal the missing data.

Methods and Materials

Method – Statistical deconstruction of the glove certification sizing specifications

Material – NFPA Standard 1971 (Fall 2007)

Results & Discussion

The original NFPA sizing criteria was established in a three step procedure that included:

1.) establishing critical hand dimensions;
2.) glove material thickness and construction technique adjustments; and
3.) manufacturing cost consideration, to establish an efficient and comfortable fit that correlates to firefighter's hand dimensions.

Each size was differentiated by a cross tabulation quantitative method which applied one selected value as a key interval length. The sizing key interval value was 10 millimeters (mm or 1 cm) for both hand length (HL) and hand circumference (HC).

The original five size system excludes the smallest 2% and largest 2% of the population distribution as a cost factor compromise. Other hand dimensions had individual interval values assigned to them to better accommodate fit and seam allowances: 2.4-4.8 mm for finger lengths; and 2.1-6.1 mm for finger circumferences. To protect the wrist, each glove must have not less than a 50.8 mm cuff, regardless of size.

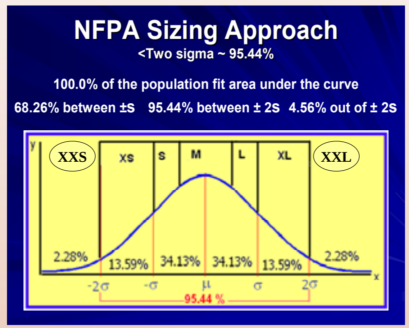
Uni-sex size categories are established from a centering point (HL and HC 50th%tile or population median) in the anthropometric data, and distributed from this central sizing point {starting at size medium (M)} in a lineal stepwise fashion to the two adjacent lower or higher sizes.

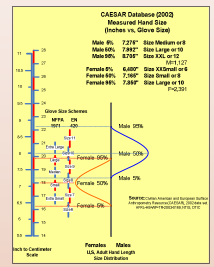
Multiple layers of fabric and leather are combined (outer shell, moisture barrier, and inner liner) to construct a glove. Fabrication requires extra materials for seam allowance and variation in the achievable manufacturing quality of the final product.

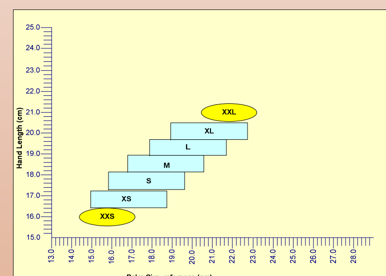
The data missing from the standard can be estimated based on the existing interval and manufacturing tolerance scheme which contain size, fit, and manufacturing tolerance accommodations.

Hand Circumference or Length Rooted System
Designed from the Mean
Into equally sized divisions

Hand Circumference	1.0 cm based scheme		Hand Length
cm	NFPA 1971	Size	cm
1.00			1.00
17.25	XX-Small	-3	15.75
18.25	X-Small	-2	16.75
19.25	Small	-1	17.75
20.25	Medium	0	18.75
21.25	Large	+1	19.75
22.25	X-Large	+2	20.75
23.25	XX-Large	+3	21.75







NFPA Standard: 1971 (2007)	Glove Type: Structural & Proximity	SIZE XXS mm (Mid-Size Value)	Tolerance +/- mm	SIZE XS mm (Mid-Size Value)	Tolerance +/- mm	SIZE S mm (Mid-Size Value)	Tolerance +/- mm	SIZE M mm (Mid-Size Value)	Tolerance +/- mm	SIZE L mm (Mid-Size Value)	Tolerance +/- mm	SIZE XL mm (Mid-Size Value)	Tolerance +/- mm	SIZE XXL mm (Mid-Size Value)	Tolerance +/- mm
thumb	Digit 1 circumference			6.17	0.57	6.4	0.57	7.01	0.64	7.26	0.65	7.52	0.64		
index	Digit 2 circumference			6.06	0.57	6.29	0.56	6.82	0.50	7.03	0.51	7.25	0.51		
middle	Digit 3 circumference	?	?	6.08	0.55	6.31	0.56	6.83	0.57	7.1	0.56	7.36	0.57	?	?
ring	Digit 4 circumference			5.69	0.57	5.92	0.57	6.34	0.56	6.6	0.56	6.86	0.56		
little	Digit 5 circumference			5	0.52	5.22	0.52	5.63	0.54	5.85	0.54	6.06	0.54		
	Digit 1 length			4.94	0.58	5.31	0.58	5.63	0.63	5.87	0.63	6.11	0.64		
	Digit 2 length			6.44	0.68	6.89	0.68	7.11	0.61	7.49	0.61	7.86	0.61		
	Digit 3 length	?	?	7.29	0.58	7.71	0.59	8.07	0.51	8.54	0.52	9.02	0.52	?	?
	Digit 4 length			6.78	0.64	7.19	0.64	7.61	0.47	8.03	0.47	8.44	0.47		
	Digit 5 length			5.09	0.57	5.44	0.57	5.78	0.63	6.13	0.62	6.48	0.62		
	Hand circumference	?	?	18.25	1.91	19.25	1.91	20.25	1.91	21.25	1.91	22.25	1.91	?	?
	Hand length			16.75	0.48	17.75	0.48	18.75	0.48	19.75	0.48	20.75	0.48		

NFPA Standard: 1971 (2007)	Glove Type: Structural & Proximity	SIZE XXS mm (Mid-Size Value)	Tolerance +/- mm	SIZE XS mm (Mid-Size Value)	Tolerance +/- mm	SIZE S mm (Mid-Size Value)	Tolerance +/- mm	SIZE M mm (Mid-Size Value)	Tolerance +/- mm	SIZE L mm (Mid-Size Value)	Tolerance +/- mm	SIZE XL mm (Mid-Size Value)	Tolerance +/- mm	SIZE XXL mm (Mid-Size Value)	Tolerance +/- mm
thumb	Digit 1 circumference	5.94	0.57	6.17	0.57	6.4	0.57	7.01	0.64	7.26	0.65	7.52	0.64	7.78	0.64
index	Digit 2 circumference	5.83	0.57	6.06	0.57	6.29	0.56	6.82	0.50	7.03	0.51	7.25	0.51	7.47	0.51
middle	Digit 3 circumference	5.85	0.55	6.08	0.55	6.31	0.56	6.83	0.57	7.1	0.56	7.36	0.57	7.62	0.57
ring	Digit 4 circumference	5.46	0.57	5.69	0.57	5.92	0.57	6.34	0.56	6.6	0.56	6.86	0.56	7.07	0.56
little	Digit 5 circumference	4.78	0.52	5	0.52	5.22	0.52	5.63	0.54	5.85	0.54	6.06	0.54	6.29	0.54
	Digit 1 length	4.57	0.58	4.94	0.58	5.31	0.58	5.63	0.63	5.87	0.63	6.11	0.64	6.35	0.64
	Digit 2 length	5.99	0.68	6.44	0.68	6.89	0.68	7.11	0.61	7.49	0.61	7.86	0.61	8.23	0.61
	Digit 3 length	6.87	0.58	7.29	0.58	7.71	0.59	8.07	0.51	8.54	0.52	9.02	0.52	9.50	0.52
	Digit 4 length	6.37	0.64	6.78	0.64	7.19	0.64	7.61	0.47	8.03	0.47	8.44	0.47	8.85	0.47
	Digit 5 length	4.74	0.57	5.09	0.57	5.44	0.57	5.78	0.63	6.13	0.62	6.48	0.62	6.83	0.62
	Hand circumference	17.25	1.91	18.25	1.91	19.25	1.91	20.25	1.91	21.25	1.91	22.25	1.91	23.25	1.91
	Hand length	15.75	0.48	16.75	0.48	17.75	0.48	18.75	0.48	19.75	0.48	20.75	0.48	21.75	0.48

Conclusion

Current sizing schemes for certified gloves worn by US firefighters include three sizing standards for latex/polymer medical gloves (NFPA 1999), one sizing standard for technical rescue gloves (NFPA 1951), one standard for leather wildland fire gloves (NFPA 1977), and one standard for the gloves used for structural and proximity fire fighting (NFPA 1971). The sizing criteria used in NFPA Standard 1971 was originally established in 1976 and was based on the hand anthropometry of male and female Air Force personnel collected during 1969 -1970 *(Coletta, et.al. The development of criteria for firefighter gloves; Vol. II: Glove criteria and test methods. NIOSH-1976)*.

This performance standard remained unmodified from its original uni-sex scheme until the fall of 2007, when two additional glove sizes were added to the original five size scheme (XS, S, M, L, and XL). However, the 2007 revision did not provide the specific sizing criteria for its two newest sizes (XXS and XXL). To fill in the missing sizing criteria, this presentation explores how the original data was statistically devised, and uses the same technique to reveal the missing data. The original sizing criteria was established in a three step procedure that included: 1.) establishing critical hand dimensions; 2.) glove material thickness and construction technique adjustments; and 3.) manufacturing cost consideration, to establish an efficient and comfortable fit that correlates to firefighter's hand dimensions. Each size was differentiated by a cross tabulation quantitative method which applied one selected value as a key interval length. The sizing key interval value was 10 millimeters (mm or 1 cm) for both hand length (HL) and hand circumference (HC). The seven size system excludes the smallest 2% and largest 2% of the population distribution as a cost factor compromise. Other hand dimensions had individual interval values assigned to them to better accommodate fit and seam allowances: 2.4-4.8 mm for finger lengths; and 2.1-6.1 mm for finger circumferences. To protect the wrist, each glove must have not less than a 50.8 mm cuff, regardless of size. Uni-sex size categories are established from a centering point (HL and HC 50th percentile or population median) in the anthropometric data, and distributed from this central sizing point {starting at size medium (M)} in a lineal stepwise fashion to the three adjacent lower or higher sizes.

The 2007 revision of the Standard continues this scheme by adding two sizes to the tails of the distribution to maintain a scheme equivalent to approximately the 3rd, 10th, 25th, 50th, 75th, 90th, and 98th percentile of the original anthropometric data set. Multiple layers of fabric and leather are combined (outer shell, moisture barrier, and inner liner) to construct a glove. Fabrication requires extra materials for seam allowance and variation in the manufacturing quality of the final product. Size is allowed to vary by the following production tolerances: ±4.8 mm for hand length; ±19.1 mm hand circumference; ±4.7-6.8 mm for finger lengths; and ±5.0-6.5 mm for finger circumferences.

The data missing from the standard can be estimated based on the existing key interval size as well as selected fit and manufacturing tolerance schemes. This reconstructed model will include the following size criteria:

	XXS	±Tolerance (cm)	XXL	±Tolerance (cm)
Digit 1 circumference	5.94	0.57	7.78	0.64
Digit 2 circumference	5.83	0.57	7.47	0.51
Digit 3 circumference	5.85	0.55	7.62	0.57
Digit 4 circumference	5.46	0.57	7.07	0.56
Digit 5 circumference	4.78	0.52	6.29	0.54
Digit 1 length	4.57	0.58	6.35	0.64
Digit 2 length	5.99	0.68	8.23	0.61
Digit 3 length	6.87	0.58	9.50	0.52
Digit 4 length	6.37	0.64	8.85	0.47
Digit 5 length	4.74	0.57	6.83	0.62
Hand circumference	17.25	1.91	23.25	1.91
Hand length	15.75	0.48	21.75	0.48

Support for this Poster was provided by:

•NORA Funded Project: Improved Equipment Design Through Applied Anthropometry - DSR CAN 8110

•COTPER Funded Project: Responder Safety and Health – NIOSH-OD-EPRO CAN ZDHK

“Promoting a US based Chain Mesh Glove Sizing Standard for Meat Processing Workers”

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National Institute for Occupational Safety and Health

Abstract

The current sizing scheme for cut resistant metal mesh gloves is based on two international standards – EN:420 & EN:1082. Both were developed in Europe based on military hand size anthropometry. There are no US equivalent glove standards for cut resistant gloves. Cut resistance glove manufacturers have adapted these European standards to create the opportunity to retail metal mesh gloves in nine sizes. This poster presents analysis of hand measures from a population of 251 meat processing workers who have a hand length range between 15.3 to 23.5 cm and palm breadth ranged between 6.4 to10.2 cm. A 17 size system was derived which provides for an accommodation rate of 95.6% of the pilot study population distribution which utilizes two gender based glove sizing schemes based on a 13 mm key sizing design interval value.

Methods and Materials

Methods: A cross tabulation quantitative method was used to apply one selected value as a key sizing interval value upon two body surface length dimensions: hand length and palm breadth.

Materials: Anthropometric study of the body dimensions of a sample of 251 contemporary US male and female meat processing workers employed in the animal slaughtering and processing (pork) industry (NAICS SIC Manufacturing Industry Groups: 2011-2015: Meat Processing).

ISO ECC European Glove Consensus Standards:

EN 420-2003 – Protective Gloves

EN 1082-1-1997 – Chain mail gloves and arm guards

Safety Relevance

Meatpacking is one of the most dangerous industries in the United States. In 2003, an estimated 527,000 workers were employed in the animal slaughtering and processing industry. In 2002, the meat and poultry industry had 14.9 injuries and illnesses per 100 workers; sausages and other prepared meats plants recorded a rate of 10.9 cases; and poultry plants recorded a rate of 9.7; each exceeding the average annual rate for all manufacturing of 7.2 cases/100 Full Time Equivalents. The most common injuries are cuts, but more serious injuries, such as amputation also occur. Cut and amputation injuries occur when sharp hand tools (knife, cleaver) and power tools (saws) are used. Also, repetitive slicing can lead to increased risk of cut injuries. The injury rate from cuts and punctures in this industry was 17.9 cases per 10,000 Full Time Equivalents in 2001. Other repetitive motion injuries occurred at a rate of 22.2 cases/10,000 which exceeds the all manufacturing rate of 14.7 in 2002. Hand injuries generally account for approximately 1/3 of all injuries at work, 1/4 of lost working time, and 1/5 of permanent disability.

The percentage of Hispanic workers in this industry increases every year. The largest proportion of workers in this industry are young, male, and Hispanic (42%). These workers use cut resistant safety equipment in their daily jobs. The benefit of anthropometric knowledge contributing to better sizing of cut resistant safety equipment extends indirectly across several industrial sectors to15 million female workers, and directly to 20 million Hispanic workers.

Support for this Poster was obtained from:

NORA Funded Projects:

- Sizing Safety Equipment for Hispanic Meat Workers - DSR CAN Z6QX
- Safety Research Planning & Direction - DSR CAN 8802
- Research Development & Planning - NPPTL CAN 7457

COTPER Funded Project:

- Responder Safety and Health – NIOSH-OD-EPRO CAN ZDHK

Results & Discussion

The current sizing scheme for cut resistant metal mesh gloves is based on two international standards – EN:420 (Protective Glove Standard) and EN:1082 (Chain Metal Glove Standard). Both were developed in Europe based principally on military hand size anthropometry to accommodate northern European workers. There are no US equivalent glove standards for cut resistant gloves, or for similar wrist/arm protectors or torso aprons. Cut resistance glove manufacturers have adapted these European standards to create the opportunity to retail metal mesh gloves in nine size cohorts (XXXS, XXS, XS, S, M, L, XL, XXL, XXXL). Each size is differentiated by a cross tabulation quantitative method which applies two selected values as key interval lengths. The sizing key interval values were 10.5 millimeters (mm or 1.05 cm) for hand length (HL) and 26 millimeters (2.6 cm) for hand circumference (HC). Uni-sex size categories are established from a centering point (HL and HC 50th percentile or population median) in the anthropometric data, and distributed from this central sizing point {starting at size medium (M)} in a lineal stepwise fashion to the four adjacent lower or higher sizes. The HC distribution maintains a scheme equivalent to approximately the 1st, 3rd, 15th, 25th, 50th, 75th, 85th, 97th and 99th percentile of the original anthropometric data set. The nine size system excludes the smallest 1% and largest 1% of the population distribution as a cost factor compromise. Fabrication of chain mail gloves requires extra materials for finger size allowance and variation in the manufacturing quality of the final product. Size is allowed to vary by the following production tolerances: ±8-51 mm for hand length.

Hand Length		metal mesh glove 2.6 cm based scheme		Hand Circumference	
	mm	EN420/EN1082		mm	
Size	10.5			26	Size
4	138	XXX-Small	-4	100	4
5	149	XX-Small	-3	126	5
6	160	X-Small	-2	152	6
7	171	Small	-1	177	7
8	182	Medium	0	203	8
9	192	Large	+1	228	9
10	204	X-Large	+2	254	10
11	215	XX-Large	+3	280	11
12	22.6	XXX-Large	+4	306	12

EN 420 is based upon a 2.6 cm HC key Interval Value and a 1.05 cm HL key Interval Value

A pilot study to determine the hand anthropometry of US meat processing workers was undertaken in 2008. 251 meat processing workers of both genders and mixed ethnicity was measured to determine if a sizing system equivalent to EN 1082 could be devised to create a potential modern US gloves sizing standard that would accommodate both males and females with a high accommodate rate. In this pilot, 50% of the workers measured were Hispanic to better simulate the modern American workforce in the meat processing trades.

Glove sizing schemes were created where each size is differentiated by a cross tabulation quantitative method which applies one selected value as the key interval length. The sizing key interval value (IV) was 13 millimeters (mm or 1.3 cm) for both palm breadth (PB) and hand length (HL). Manufacturers of high performance gloves often use an IV between 0.6 and 1.3mm. This considers the typical diameter of individual links in the chain mail (outside diameter = 4mm) that are needed to create a seam, i.e., 3 links, or approximately 12 mm, which should promote better fit tolerances. Gender based size categories are established from a centering point (HL and PB 50th percentile or population median) in the anthropometric data, and distributed from this central sizing point {starting at size medium (M)} in a lineal stepwise fashion to the four adjacent lower or higher sizes.

Males

	PB	HL 13.9-15.2	15.2-16.5	16.5-17.8	17.8-19.1	**19.1-20.4**	20.4-21.7	21.7-23.0	23.0-24.3	24.3-25.6
	13.6-14.9									
	12.3-13.6									
	11.0-12.3									
	9.7-11.0					3	4	4		
PB	**8.4-9.7**		1	2	32	48	27	5		HL PB
	7.1-8.4			3	4	6	3	4	Median	19.7 9.0
	5.8-7.1					1			Std. Dev.	1.28 0.53
	4.5-5.8								Maximum	22.9 10.5
	3.2-4.5								Minimum	15.3 6.9
		%	0.01	0.03	0.23	0.41	0.24	0.08		
		#	1	5	36	58	34	13		n= 147

12 sizes 97.2% Accommodation

Females

	PB	HL 12.1-13.4	13.4-14.7	14.7-16.0	16.0-17.3	**17.3-18.6**	18.6-19.9	19.9-21.2	21.2-22.5	22.5-23.8
	12.4-13.7									
	11.1-12.4									
	9.8-11.1									
	8.5-9.8						6	2		
PB	**7.2-8.5**				30	38	20	1		HL PB
	5.9-7.2			3	2	2			Median	17.9 7.8
	4.6-5.9								Std. Dev.	1.0 0.4
	3.3-4.6								Maximum	20.9 8.7
	2.0-3.3								Minimum	15.7 6.4
		%	0.00	0.03	0.31	0.38	0.25	0.03		
		#	0	3	32	40	26	3		n= 104

5 sizes 93.2% Accommodation

The HL:PB distribution maintains a scheme equivalent to approximately the 1st, 3rd, 15th, 25th, 50th, 75th, 85th, 97th and 99th percentile of the original anthropometric data set. After applying the design scheme to Group, Male and Female measurement data within the anthropometry data set, a best fit accommodations analysis was determined to learn which single, combination or overlapping fit models achieved the highest level of accommodation. Any cell data cohort with less than 2% of the population distribution was excluded from the size forecast as a cost/manufacturing quality factor compromise.

Group

	PB	HL 13.3-14.6	14.6-15.9	15.9-17.2	17.2-18.5	**18.5-19.8**	19.8-21.1	21.1-22.4	22.4-23.7	23.7-25.0
	13.6-14.9									
	12.3-13.6									
	11.0-12.3									
	9.2-11.0				3	17	19	12	1	
PB	**7.9-9.2**		1	9	41	51	32	7	1	
	6.6-7.9		1	19	19	11	3	2	1	
	5.3-6.6				1					
	4.0-5.3									
	2.7-4.0									
		%	0.01	0.11	2.65	0.31	0.22	0.09	0.01	
		#	2	28	64	79	54	21	3	

11 sizes 94.8% Accommodation n= 251

Female to Male Overlay

	PB	HL 13.9-15.2	15.2-16.5	16.5-17.8	17.8-19.1	**19.1-20.4**	20.4-21.7	21.7-23.0	23.0-24.3	24.3-25.6
	13.6-14.9									
	12.3-13.6									
	11.0-12.3									
	9.7-11.0					3	4	4		
PB	**8.4-9.7**		1	3 2	7 32	5 48	1 27	5		
	7.1-8.4		3	39 3	30 4	11 6	3	4		
	5.8-7.1		3		2	1				
	4.5-5.8									
	3.2-4.5									
		%	0.03	0.19	0.30	0.29	0.14	0.05		
Counts:		#	7	47	75	74	35	13		n= 251

Red = Female

Blue = Male

8 sizes 88.8% Accommodation

Male to Female Overlay

	PB	HL 12.1-13.4	13.4-14.7	14.7-16.0	16.0-17.3	**17.3-18.6**	18.6-19.9	19.9-21.2	21.2-22.5	22.5-23.8
	12.4-13.7									
	11.1-12.4									
	9.8-11.1							4	3	
	8.5-9.8			1	1	18	6 49	2 35	13	2
PB	**7.2-8.5**				30 1	38 3	20 7	1 4	4	1
	5.9-7.2			3	2	2		1		
	4.6-5.9									
	3.3-4.6									
	2.0-3.3									
		%		0.02	0.14	0.24	0.33	0.19	0.08	0.01
		#		4	34	61	82	47	20	3

8 sizes 90.4% Accommodation n= 251

Summary & Conclusion

Body measures from the worker population sample had a hand length range between 15.3 to 23.5 cm and palm breadth ranged between 6.4 to10.2 cm. Hand sizes between males and females were significantly different and overlapped in very few sizes. Models which attempted to merge gender into a single uni-sex sizing system (whether Group, Male to Female or Female to Male) produced lower fitting accommodation percentages.

The best model for the highest accommodation level, based on this data set, would be two separate glove sizing systems – one for male and one for female. After adjusting for gender, a 17 size system would be achieved which provides for an accommodation rate of 95.6% of the pilot study population distribution, and would include 12 separate sizes for males and 5 separate sizes for females.

There are no US consensus standards for the of sizing metal mesh gloves. Currently available gloves used in this industry are sized and labeled based on the European sizing scheme which was developed for the European worker population. There are no US or European consensus standards for sizing cut resistant wrist protectors, arm protectors, or aprons used in the meat processing industry. These forms of safety equipment are sold based on labeling systems that use generic uni-sex sizing systems adopted by each manufacturer. End-users must use trial-and-error methods to select these types of safety apparel. The data from this study will be useful in developing sizing standards for personal protective equipment for meat processing workers that better accommodate the size and shape of today’s US workforce. Gender based sizing has the potential to provide improved protection from laceration injury and improved fit.

Effect of an Exposure-Indicating Light on Noise Reduction Experienced During Work at a Factory

NIOSH Mining Occupational Safety and Health Research Grant

John A. Frazer, MS; Steven Guffey, Ph.D., CIH; Brandon C. Takacs, MS; Mingyu Wu, MS
Industrial Engineering, West Virginia University College of Engineering and Mineral Resources, Morgantown, WV

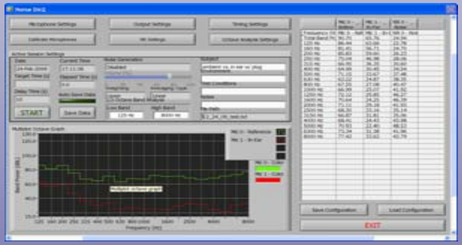
Research Focus

This project was made possible through a National Institute for Occupational Safety and Health (NIOSH) Mining Occupational Safety and Health Research Grant to study real time hearing protector insertion loss. Steven E. Guffey, Ph.D., CIH is the Principal Investigator.

Introduction

It is very likely that worker protection provided by hearing protection devices (HPD) is diminished by failure to wear them when needed and by failure to seat them properly during use. For those reasons, encouraging workers to wear their HPD is an important part of hearing conservation programs. Use of HPD is also encouraged by disciplinary procedures, including firing. A more positive behavioral modification is simply alerting workers immediately when their HPD fail to protect their hearing. It is possible that workers sometimes (1) forget to re-install the HPD after removing it temporarily, (2) underestimate the cumulative effects of "temporary" non-usage, and (3) underestimate the noise level. If so, it is possible that immediate feedback of their exposure would both alert them and prod them to re-don their HPD when alerted of high noise levels in their ears.

Custom Written Labview Data Acquisition Software



Exposure Indicating Light

Tubing Assembly

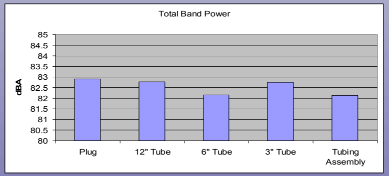
Methods

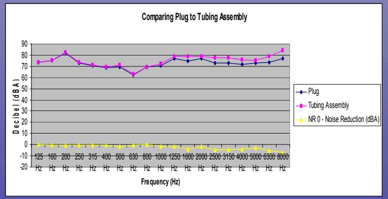
It is possible that workers would wear HPD more effectively if they knew exactly when the dose to their ears were excessive. To test that theory, each of 20 workers in an industrial operation who worked in noisy environments wore a hardhat with a light on its brim. The light shown whenever noise proximal to the HPD (SPLear) exceeded 80 dBA by a doseBusters dosimeter. Noise levels were also measured with separate data-logging Larson-Davis dosimeters proximal to the HPD and at the shoulder (SPLsh). For each worker, during some periods of work the light was allowed to activate and at other times the light was switched off so that no alert would be given. To ensure that the worker knew the light would not alert during high exposures, a black plastic cap was placed on the light during those periods. Using the SPLear and SPLsh data logged at times when SPLsh exceeded 85 dBA, the noise reduction (NR) achieved during alerted periods was compared to values obtained during periods when the light was inactivated. The total doses in the ear during periods of low NR values also were compared for the two test conditions.

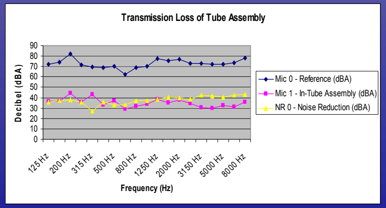
Subject Donning Exposure Indicating Light Helmet with Plugs Inserted

Subject Donning Exposure Indicating Light Helmet with Plugs Removed

Probed Microphone Comparisons





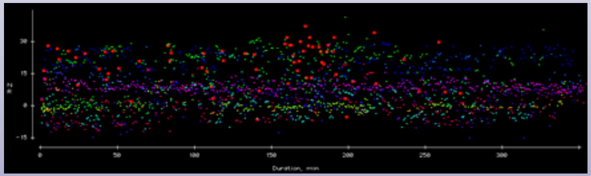


Results

The results were mixed. Three of the twelve tested workers clearly wore their HPD nearly all the time, so that it was impossible to improve HPD performance during their work shift. Conversely, three workers showed very poor NR values during both periods, demonstrating either indifference or that the HPD simply did not protect very well. One of the tested workers experienced an equipment failure and therefore was excluded from the data. For the remaining five workers, the light appeared to improve compliance. For them, NR when SPLsh exceeded 85 dBA averaged 8 dBA without the light and 14 dBA with the light.

Preliminary Conclusions

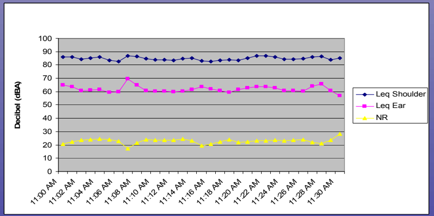
The data collection and report of findings are in progress. Preliminary analysis of data leads these researchers to believe that the exposure indicating device is moderately effective for those who needed reminding or had a moderate to poor fit.



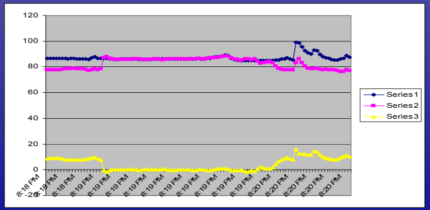
Subject Time-Series of SPL Ear, SPL Shoulder & Noise Reduction

Table of Preliminary Results

Subject	MeanOFF	MedianOFF	75%OFF	90%OFF	StdDevOFF	MeanOn	delNR	Fit
1	20	22	20	28	9	19	0	Great
2	-2	-2	-2	4	5	4	6	Awful
3	9	9	9	13	2	9	0	
4	0	2	0	9	8	5	5	
5	16	18	16	26	9	20	4	
6	19	18	19	26	5	18	-1	Great
7	0	-1	0	10	6	1	0	Awful
8	8	5	7	21	8	16	8	
9	18	22	19	28	10	24	6	Great
11	0	0	0	1	1	1	2	Awful
12	-1	-2	-2	7	4	0	0	Awful



Subject Time Series of Removing and Reinserting Plugs



Noise Reduction Versus Time for All Subjects

National Institute of Occupational Safety and Health Funded Study (1 R01 OH008723)
Real Time Hearing Protector Insertion Loss

Comparison of Noise Reduction Values for Fit-test and Work in Coal Mines

NIOSH Mining Occupational Safety and Health Research Grant

Mingyu Wu, MS; Steven E. Guffey, Ph.D., CIH; Brandon C. Takacs, MS

Industrial Engineering, West Virginia University College of Engineering and Mineral Resources, Morgantown, WV

Introduction

It is not clear how effective fit-tests done in an office environment are in predicting the noise reduction (NR) afforded individual coal miners by the same hearing protectors during actual work. It is also not clear how much of internal noise doses can be attributed to failure to wear hearing protective devices (HPD) and how much to failure to wear HPD properly.

The specific aims of this study were to determine:

(1) if noise dosimeters can replace a real-time analyzer to determine NR for fit-test for an individual; that is, find out if the NR measured from two dosimeters is comparable to that measured with a real-time analyzer.

(2) within and between subject differences in NR due to repeated fit tests.

(3) within and between subject differences in NR during work

(4) the proportion of exposure dose attributable to failure to wear HPD and failure of the HPD to protect.

(5) whether a single fit-test value of HPD can represent the NR for an individual at work as well as the average of 12 fit-tests.

Methods

Seventeen miners from four coal mines (prep-plant and underground coal mine) participated in the study.

The miners were fit-tested, using both a National Instrument (NI) real-time noise analyzer and a pair of Larson Davis dosimeters at the mining facility, in an ordinary office room. The subject sat on a chair approximately 50 cm in front of a speaker emitting pink noise, surface, or underground noise. Each miner donned a HPD, either earmuff or earplug, then removed it again before the next replication to test refitting of the HPD. The miners NR was calculated at 0, 90, and 180 deg from the noise source.

During all tests, miners who normally wore muffs wore their normal (cap-mount) ear muff. For miners who normally wore ear plugs, each wore investigator-provided EAR plugs modified to allow a small microphone to penetrate through them.

During normal shift work the same day, the same coal miners wore the same two dosimeters with same microphone setting to record the NR; that is, one microphone was proximal to the HPD (SPLear) and the other was on the shoulder (SPLsh).

All values were logged with time-stamps every second. The researches examined every minute NR integrated from every second to evaluate the coal miners' noise protection.

Fig. 1: Ear Plug Fit-Test

Fig. 2: Earplug NR measurement in field

This project was made possible through a National Institute for Occupational Safety and Health (NIOSH) Mining Occupational Safety and Health Research Grant (1 R01 OH008723).

At opportune times, investigators noted whether an individual miner was wearing his HPD or not, allowing development of an algorithm that associated patterns of NR values with failure to wear the HPD. With the developed wearing status judgment method, the researches were able to determine coal miners' HPD wearing status (on or off) and calculate the noise dose increase due to non-wearing status.

Results

The individual fit-test NR for each one of the coal miners often varied by more than 8 dB, indicating that the main variability of the fit-test NR is not from tested ear orientation. The orientation of the subject's HPD in relation to the noise source and type of HPD was not significantly different except for earmuff 180 degree, 1.5 dB. Therefore, any single fit-test result cannot represent a real NR of a miner's HPD. In addition, the average NR from analyzer and dosimeter are 17 and 17.5 dB, respectively, with a confidence interval (-2.4, 1.3), although individual NR values from these two instruments differed. This indicated that the analyzer and dosimeters produced indistinguishable results.

As shown in Figure 6, blue are cases of disagreement between judged and observed wearing status. The accuracy of wearing status judgment was 98%.

Table 1: NR Comparison between group means for Fit Test and Field

HPD	Fit testing or field	Mean	StdDev
earmuff	fit testing	19.2	6
	field	16.4	6.8
earplug	fit testing	16.5	4.8
	field	16.8	5.6

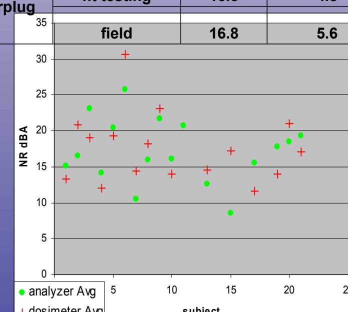


Fig. 4: NR Comparison between Analyzer and Dosimeter

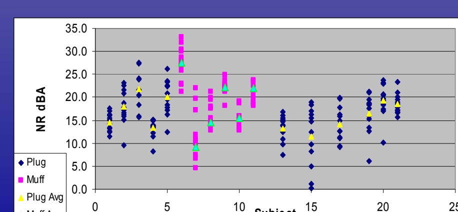


Fig. 5: Miner subjects' NR Fit Test values

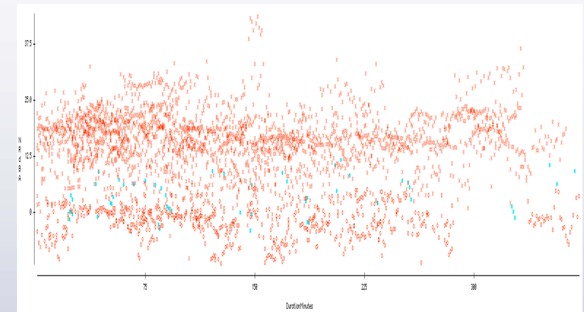


Fig. 6: Duration (min) vs. NR- compare wearing status for judged and observed in field

Even when periods of non-HPD use were removed, the results showed variability of NR values for all miners during their work shift. The between and within subject variability were high but only marginally higher than the same values for fit-test. Statistical analyses showed that group fit-test NR values were close to the group work NR values, Table 1. However, individual fit-tests were only modestly successful predictors of individual work NR values, accounted for only about 25% of the between-subjects variability. The noise dose increased by 11% due to non-HPD use for the group of workers.

Conclusions

The preliminary conclusions from this study are that for the subjects tested here:

1)failure to wear HPD accounted for only a modest fraction of dose measured at the ear,

2)both fit-test results and work NR values were highly variable both between and within subjects,

3)a single fit-test is likely to be a highly unreliable indicator of actual protection during work, and

4)the mean of 12 fit-tests can only be used with confidence to judge gross acceptability of a HPD.

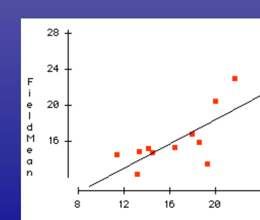


Fig 7: Earplug NR comparison between fit-test and field for each miner subject

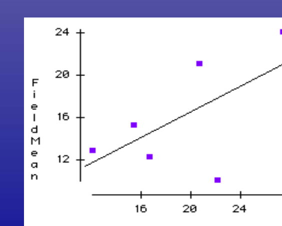


Fig 8: Earmuff NR comparison between fit-test and field for each miner subject

Improved Design of Kneepads for Low-seam Mining

Background

- In 2007, 227 knee injuries were reported to MSHA for underground coal.
- The median days lost due to a knee injury in coal operations is 41 days.
- The average cost per knee injury is $13,121.29.
- Thus, for 2007, the financial burden of knee injuries was nearly $3 million.
- Therefore, there exists a need to improve the design of kneepads currently utilized in underground coal industry.

Study Objective

- No standards exist in the United States for the design of kneepads for occupational needs.
- As a result, many types of kneepads exist and their efficacy is unknown. (**Figure 1**)
- Our laboratory has developed experimental methods to measure the efficacy of kneepads by evaluating the forces, stresses, and moments at the knee while in postures associated with low-seam mining.

The objective of this study is to design a kneepad that places less stress on ligaments and soft tissues of the knee than existing kneepads.

A prototype kneepad will be fabricated and tested in the laboratory and field environments to quantitatively demonstrate the improved function of this new kneepad design.

Figure 1. Four kneepads used for underground mining showing vast differences in design

Overview of Approach

Forces, stresses, and moments at the knee while in postures associated with low-seam mining (Figures2 & 3)

Postures
Postures to be included were selected based on observational studies and from interviews with mine safety and health personnel and mine workers

Kneepads
Postures simulated with and without typical kneepads being used in the industry to determine the effectiveness of current kneepad designs

Experimental Procedures
Motion Analysis System – measure postures
Capacitive sensor technology – measure pressure at knee
Force plates – measure forces applied to foot and knee
Computation model #1 – calculate net forces and moments at the knee
Computational model #2 – calculate forces of internal stabilizing structures of knee

Develop novel kneepad and evaluate through laboratory and field testing

Prototype
Specifically designed to reduce forces, stresses, and moments at the knee as measured experimentally

Current data demonstrates that key anatomic landmarks are transmitting nearly all the stresses and forces to the knee

Laboratory Testing
Test prototype kneepad in laboratory to demonstrate a larger reduction in forces, stresses, and moments at the knee when compared to kneepads currently used in the industry

Field Testing
Evaluate mine worker impressions of prototype immediately following implementation and at 1, 3, 6, and 12 months following

Investigate durability, acceptance by mine workers, and determine any necessary alterations to the design

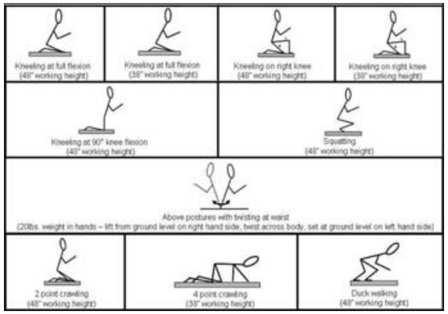


Figure 2. Postures evaluated in laboratory study

Figure 3. Subject simulating mining posture

We would like to acknowledge our many collaborators on this project:

- University of Pittsburgh
- Rockwood Casualty Insurance Company
- Parkwood Resources
- Rox Coal
- TJS Mining
- East Fairfield Coal Company

Causal Factors for Pesticide-related Illness: Five years monitoring WA agricultural workers (2003-2007)

By Barbara Morrissey, Tito Rodriguez, Mario Magaña
WA State Department of Health, Pesticide Program: Illness Monitoring and Prevention

Introduction:

In Washington State, pesticide-related illnesses are a reportable condition. The WA Department of Health (DOH), Pesticide Program investigates reported cases to identify and target prevention activities. From 2003-2007, DOH documented 248 cases among agricultural workers that were plausibly related to agricultural pesticides.

- The majority (141) were pesticide handlers (defined as being a pesticide mixer, loader, applicator, or involved in maintenance and repair of contaminated equipment).

- Other agricultural workers were orchard thinners (24 cases), harvesters (20), irrigators (12), pruners or tying fruit trees (11), general farm labor (12) ornamental nursery workers (16), vineyard workers (6) and foreman or supervisors (4). Data on possible casual factors for these illnesses are detailed below.

Methods:

- The WA surveillance system captures mostly cases that have sought some type of medical care. The surveillance system can not report on the number of agricultural workers who fall ill from occupational pesticide exposure but do not seek health care.

- DOH bilingual investigators gather information about the reported exposure and the health outcome from phone interviews with the worker, spray records, and medical records. The information is stored in the WA Pesticide Illness Monitoring System (PIMS) database.

- For this data set, PIMS was queried for cases involving agricultural workers from 2003-2007. Cases classified as Definitely, Probably, and Possibly related to a pesticide exposure were included in the analysis. Cases considered suspicious or insufficient information were not included.

Number of agricultural workers/year documented by WDOH, Pesticide Program

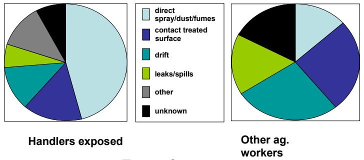
	2003	2004	2005	2006	2007	Total
Handlers	27	33	28	26	27	141
Other Ag. workers	28	17	36	9	17	107
Total	55	50	67	35	44	248

Who is getting sick?

Demographics of ag. workers with pesticide related illness/injury

	Handlers (n =141)	All other ag. Workers (n=107)
Gender	98% male	56% male
% Hispanic	82% Hispanic	87% Hispanic
Preferred language	71% prefer Spanish	82% prefer Spanish
Age (median, range)	33 (17-74) years old	33 (14-65) years old
Task when exposed	Mostly applying pesticide	Thinning, harvesting
Severity of illness/injury	87 % mild, 13% moderate/severe (1 severe case in each group)	

How are they being exposed?

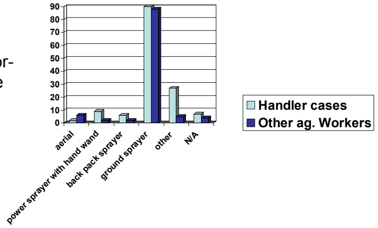


Type of exposure

- Handlers are being primarily exposed to sprays, mists, and dusts during the application.

- Other workers are primarily exposed through pesticide drift and residues on treated foliage.

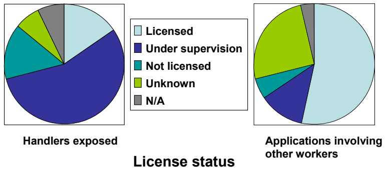
Type of equipment involved in reported cases is mostly tractor-pulled ground sprayers like the orchard air blast sprayer.



License status of applicator:

- 87% of ground sprayers were licensed or under supervision of licensed person.

- Majority of exposures linked to an application involved a licensed or supervised applicator.

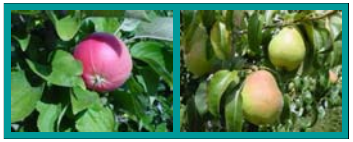


License status

Crop type:

51% of handlers and 52% of other ag workers were exposed to pesticides applied to pome fruits (mostly apples).

Pome fruits:

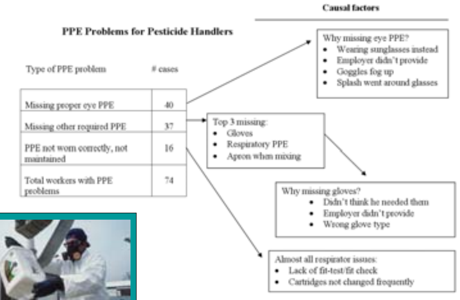


Acknowledgements:
NIOSH Pesticide SENSOR
Nancy West, Department of Health

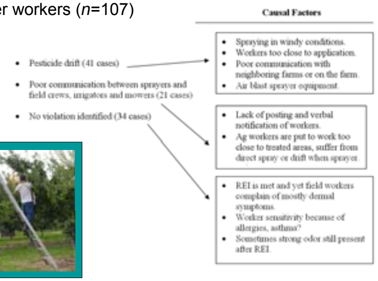
Why are workers being exposed?

Causal factors for handlers (*n*=141)

52% of handlers were missing at least one required piece of personal protective equipment (PPE) or were wearing poorly fitting or poorly maintained PPE.



Causal factors for other workers (*n*=107)



Prevention: Target group and prevention messages

1. Male Hispanic handlers working in tree fruit (Spanish speaking).
   - Important to wear all required PPE (especially goggles, gloves).
   - Check the fit of your goggles and respirator every time.
   - Important to communicate with foremen of other work crews, irrigators on farm.
   - Spray drift from air blast sprayers can travel far especially when trees are bare. Make sure thinners and other workers are a safe distance.
2. Male and female Hispanic field workers (in Spanish speaking).
   - If a sprayer comes near your work area, find your foremen and move.
   - Report drift to your foremen and decontaminate exposed skin and clothes.
3. Employer outreach:
   - Provide workers with all PPE required on pesticide label.
   - Keep workers out of harms way: facilitate communication between spray crews and others.
   - Notify adjacent farms when spraying blocks along the property line.
   - Ensure that unlicensed handlers receive good supervision.
4. EPA:
   - Review REIs to ensure they are protective
   - Give guidance for safe distance from orchard air blast

NIOSH/PRL Innovations to Improve Hearing Protection

NIOSH Decibel Dummy

- Educational tool to demonstrate noise exposure concepts
- Inexpensive – based on Styrofoam mannequin head and VU meter kit.
- Enhanced with NIOSH-designed A-weighting circuit
- Microphones in each ear linked to sound level LEDs in each eye: Blink red (high) yellow (medium) and green (low)
- High sensitivity (red = 70 dBA) for demonstrations at moderate sound levels; low sensitivity (red = 85 dBA) for demonstrations with potentially hazardous noise

Some possible demonstration scenarios:

- Proper and improper HPD use
- Benefits of sound barriers inserted between noise sources and dummy
- Asymmetric exposures (open car window, etc.)

NIOSH MultiFit Earplug Fit Research System

- Tests four subjects at a time
- Mobile – will be installed in NIOSH Hearing Loss Prevention Unit
- Flexible software allows multiple training and feedback scenarios
- Replicates ANSI S12.6 methodology through headphones
- Laboratory-grade instrumentation

NIOSH Sound Restoration Earmuff Evaluation

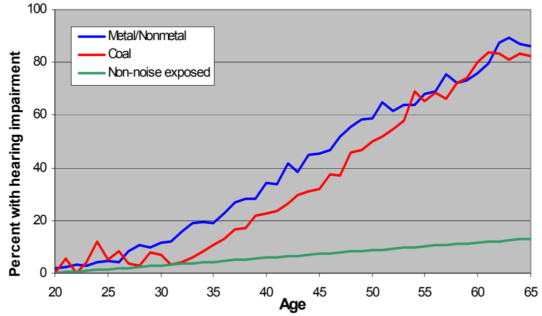
- Developing standard method to evaluate performance of sound restoration earmuffs
- Evaluating performance characteristics of currently available products
- Will provide guidance on use of sound restoration earmuffs in various noise environments

NIOSH QuickFit Earplug Tester

- Simple test for adequate (15dB) protection
- Inexpensive — based on earmuff and voice recorder circuit
- Test signal — standard 1KHz octave band noise
- 15dB boost used for go/no-go check of adequate protection
- More reliable and accurate than subjective self-checks
- Can be used at *any* worksite *every* time earplugs are worn

NIOSH/PRL Motivational and Training Solutions for Hearing Loss Prevention

Problem:
High rates of hearing loss among mine workers



Source: Franks, 1996, 2002

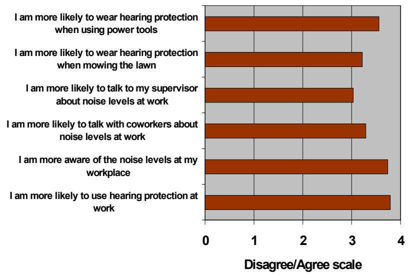
Motivational Solution:
NIOSH Hearing Loss Simulator

Windows software

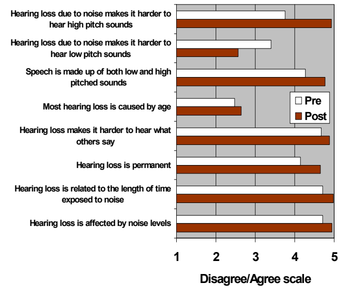
Web Samples

Evaluation

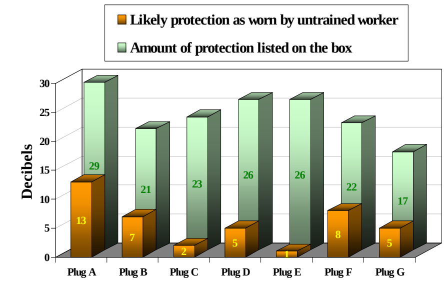
Change in Behavioral Intentions

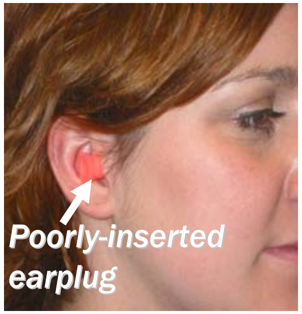


Change in Attitudes & Beliefs



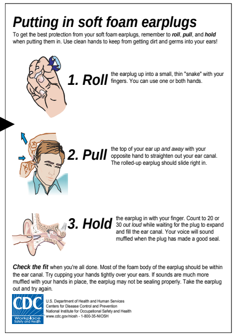
Problem:
Hearing protectors used incorrectly





Informational Solution:
Simpler Roll-Pull-Hold technique

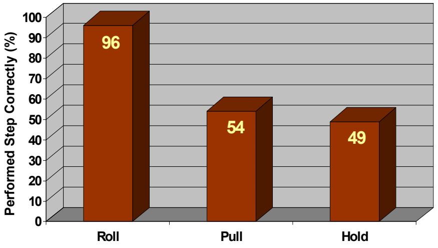
Manufacturer's instructions



NIOSH Roll-Pull-Hold instructions

Evaluation

Successful completion of Roll-Pull-Hold steps



Improved protection